Air-Cooled Condensers in Next-Generation Conversion Systems

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May 18, 2010

Track: Specialized Materials and Fluids and Power Plants
Project Overview

• Timeline:
  – Start Date: October 2009
  – End Date: September 2011
  – ~15% Complete

• Budget:
  – FY2010: $375K
  – FY2011: $435K

• Barriers:
  The impact of air-cooling on plant performance and the costs of air-cooled condensers are barriers that will impact DOE’s goal to develop low-cost conversion systems that are more efficient for both EGS and low-temperature resources.

• Partners: None
Relevance/Impact of Research:

• The overlying objective is to reduce the costs associated with the generation of electrical power from air-cooled binary plants

• Premise for this work: No water is available for evaporative cooling

• Issues with Air-Cooling
  – Amount of heat rejected – up to ~90% of heat added is rejected
  – Cost - 30 to 45% of Capital Equipment Cost (EPRI Next Generation Geothermal Power Plant study)
  – Fan power - up to 10% of generator output
  – Sensitivity to temperature change: @150°C ~1.4% Δavailable energy per °C Δair temperature
Relevance/Impact of Research:

- Plant performance: function of source and sink temperatures, and conversion efficiency
- Conversion efficiency degrades with deviation from design temperatures
- Focus is on
  - Minimizing the effect of temperature changes on conversion efficiency
  - Increasing conversion efficiency by using mixed working fluids
Scientific/Technical Approach

- Assume no consumptive use of water
- Two resource scenarios (200° and 150°C); two representative locations (Grand Junction CO and Houston TX)

Design Conditions

- Design condition: maximum net power for each scenario — resource temperature, location and outlet temperature constraint
  - Fixed geothermal fluid flow rate
  - Working fluids: iC5, iC4, nC4, C3, R134a, R245fa
  - Incorporate realistic operating parameters (pinch points, efficiencies, ΔP’s)
- Evaluate benefit of technologies not used in conventional hydrothermal plants
- Estimate capital cost based on predicted equipment sizes
Scientific/Technical Approach - continued

Off-Design:

• Fix equipment sizes for selected design condition
• Include effect of flow and temperature changes on heat transfer coefficients, efficiencies, ΔP’s
• Account for effect of turbine on working fluid flow
• Identify conditions giving maximum power for different ambient and resource temperature conditions.
• Project power production over project life
• Evaluate the potential to decrease generation costs
  – Selection of design conditions for ambient and turbine
  – Other concepts (changing working fluids, allowing expansions inside two-phase region)
Scientific/Technical Approach - continued

Working Fluid Mixtures:

- Evaluate effect of composition and tube orientation on condensing film coefficient
  - Test data from Heat Cycle Research Facility
  - Tube orientations of 90° (vertical), 60°, and 15°
  - Isobutane and hexane mixtures (0 to 15% hexane)
  - Propane and isopentane mixtures (0 to 40% isopentane)

- Use data to refine predictive methods for condensing coefficients

- Integrate results into a condenser design model capable of evaluating the suitability of at least one commercially available design with these fluids

- Identify any potential issues with the design and provide recommendations
Scientific/Technical Approach - continued

Milestones:

- Sep 10 Complete Task 1 – Analysis of impact resource decline and ambient temperatures on air-cooled binary plant output, and the potential to mitigate those impacts with existing technologies
- Feb 11 Complete evaluation of effect of mixture composition and tube orientation on condensing film coefficients
- Sep 11 Complete Task 2 – Assessment of the suitability of existing condenser designs for mixed working fluids

Decision Points:

- The methodology used to evaluate existing condenser designs – February 2011
- Selection of the commercial design to be evaluated (will be largely dictated by the data from the prior testing) – March 2011

Status:

- Designs have been established for both resource conditions at both locations, and the benefits from a design using recuperation identified
- Fixed plant design models will be completed in early May
Accomplishments, Expected Outcomes and Progress

- Design conditions determined for both resource temperatures at each location (design at mean annual air temperature)
- Benefit of recuperation evaluated for each scenario
  - Positive impact on power only if constraint on outlet temperature
  - No benefit at lower resource temperature
- Model is being modified to fix equipment and reflect impact of varying flow rates and temperature on heat transfer, efficiencies and $\Delta$pressure

<table>
<thead>
<tr>
<th>Location</th>
<th>$T_{gf}$</th>
<th>Design with no outlet constraint</th>
<th>Design with outlet constraint</th>
<th>Design with Recuperation</th>
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<tbody>
<tr>
<td>Grand Junction</td>
<td>200°C</td>
<td>87.2 kW-s/kg</td>
<td>76.6 kW-s/kg</td>
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<td>150°C</td>
<td>41.5 kW-s/kg</td>
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<td>200°C</td>
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<td>150°C</td>
<td>32.8 kW-s/kg</td>
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<td>32.4 kW-s/kg</td>
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Accomplishments, Expected Outcomes and Progress

Mixed Working Fluids

- Non-isothermal boiling and condensing allow heat transfer irreversibility to be reduced
- Prior work by Demuth and Whitbeck
  - +20% increase in plant performance
  - Cost benefit if well field development costs equivalent to or greater than plant cost
- Vaporization of mixtures
  - Replicate benefit with pure fluid in supercritical cycles
- Condensation of mixtures
  - Can not replicate with pure fluids
  - Prior work successful – in-tube condensation, non-horizontal tube orientation, water cooled condensers

Can benefits be achieved in air-cooled condensers?
Project Management/Coordination

- With determination that final year of funding would not be provided, project work scope and schedule were revised to focus on binary conversion systems.

- Activity has been planned to maximize use of existing resources:
  - Previously developed model of binary plants
  - Software platforms (Aspen) available at the INL
  - Prior work on the evaluation of binary turbine performance
  - Test data from the Heat Cycle Research Facility (mixed working fluids)

- Work has been planned to facilitate ‘learning curve’ of staff having no prior geothermal experience.

- Cost and schedule are monitored and reported internally on a monthly basis.
## Project Management/Coordination

### Air-Cooled Condensers in Next Generation Conversion Systems

<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
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<th>2011</th>
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<td>AIR-COOLING WITH MIXED WF's</td>
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<td>1. Use prior work to establish impact of mixtures on condensing coefficients</td>
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### Spend Plan for Air Cooled Condenser Task

- **Spend Plan**
- **Actual**

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Future Direction

Remainder of FY2010

• Complete modeling of the effect of varying ambient temperatures and declining resource on binary plant output.
• Assess the selection of the design conditions for both the ambient temperature and turbine
• Identify concepts/technologies with the potential to lower generation costs
• Document findings
• Initiate work to examine condenser data from Heat Cycle Research Facility
Future Direction

FY2011

- Determine effect of mixture composition and tube orientation on condensing film coefficients during testing at the Heat Cycle Research Facility
- Use these results to evaluate predictive methods
- Incorporate best predictive method(s) into model to evaluate existing condenser designs
- Select most promising design and assess suitability for use with mixtures
- Document findings
Summary

- The heat source and sink temperatures define the maximum power a cycle can produce.
- This work seeks to minimize the impact of variations in the source and sink temperature on the performance of a plant once it has been constructed.
- Benefits of technologies that are applied to mitigate effects of off-design operation will be dependent upon the scenario evaluated.
- Working fluid mixtures
  - Increase performance and plant cost.
  - Reduce contribution of well field and reservoir to generation cost – lower generation cost if non-plant costs are significant.
  - Questions whether non-isothermal condensation can proceed in commercial condenser designs.